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COMMONWEALTH OF AUSTRALIA

Council for Scientific and Industrial Research

BULLETIN No. 194

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PACIFIC OCEANIC FISHERY
INVESTIGATIONS

A Procedure of Investigation in Fisheries Biology

(Division of Fisheries—Report No. 11.)

By

C. L. KESTEVEN, B.Sc.

MELBOURNE, 1946

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C O N T E N T S

		Page
	Summary	5
1.	INTRODUCTION	7
2.	RESEARCH AIMS	8
3.	THE OBJECTS OF INVESTIGATION -	
	(i) Fish Stocks	14
	(ii) Commercial Operations	17
	(iii) The Environment	19
4.	THE INVESTIGATIONAL PHASES	20
5.	INVESTIGATIONAL PROCEDURES -	
	(i) Biological Investigations ..	22
	(ii) Biometry and Econometry	22
	(iii) Economic Investigations	23
	(iv) Planktological Investigations ..	23
	(v) Hydrological Investigations ..	24
	(vi) The Integrated Programme	25
6.	DISCUSSION	26

SUMMARY.

Fisheries biology is devoted to the analysis of a complex system, comprising natural elements on the one hand, and economic elements on the other. Its programme can be divided into three major phases. First an exploratory phase in which the major elements are isolated and the character of their relationships examined, mainly qualitatively; second, an appraisal phase in which an effort is made to obtain more precise data on the elements and their relationships and to give greater quantitative expression to these; finally, a phase of control in which these results are applied to ensure that the fishing machinery remains in such relationship to the fish stocks that the catch is taken most economically, and maintained at the highest possible level in quantity and composition, with depletion prevented. A brief summary is given of the investigational procedures employed to this end.

A Procedure of Investigation in Fisheries Biology *

1. INTRODUCTION.

Fisheries research programmes have been conducted in practically all maritime countries of the world. Although these programmes have had one object of investigation in common, namely, increased production of fish, they have differed in their immediate objectives and in their methods, and these differences have given rise to definite 'schools' of enquiry. These schools, which represent in the main differences of emphasis upon aspects of the full possible programme, appear to depend on the speed with which the groups of investigators have accommodated themselves to the development of the theory of fisheries science; the latter has revealed itself in a number of stages related to the development of the commercial fisheries and to the accumulation of fundamental biological data. From time to time the development of the science has been outlined in major papers by leading workers. Some of these papers have formed original contributions, whilst others have been appraisals of the position reached by the science. In sum, there has emerged a science of fisheries, but the scope, capacities, and responsibilities of this science have not yet been fully stated, and the lack of such statement has had some important consequences. It is suggested firstly that the absence of this statement has influenced the direction of fisheries research, leading in many cases to an insufficient degree of co-ordination and planning. On the other hand, the absence of the statement has made it possible for numerous misconceptions to arise as to the scope and prospects of results of this research.

The present time appears to be opportune for stating the position which has been reached and for indicating the contribution which this science may be expected to make to the industry, not only in the post-war period, but also in the more distant future.

Accordingly, Table 1 has been prepared to show in schematic form the essential features of a fisheries programme in its various sections and stages. This table sets out, with only such detail as is necessary to make the plan easily comprehensible, the various investigational procedures which may be adopted at different stages in respect of various objects of enquiry (fields of enquiry or sources of data). The table relates only to the work of fisheries biology which is concerned with the fish stocks as objects of exploitation. It does not refer to technological research, which deals on the one hand with the problems of catching fish and on the other of handling, transport, and processing.

This scheme of enquiry is set out diagrammatically in Figs. 1 to 5, which are intended to show the relationship of the various sources of data and the lines along which the data must pass in order that, through treatment, they should yield conclusions in respect of the problems under investigation.

* Typescript received June 22, 1945.

2. RESEARCH AIMS.

As an ultimate result, these investigations will lead to the production of more fish, but, although this phrase is a useful one for purposes of propaganda, it is an insufficient description of the aims of the work. The objectives can be described most easily as being the answers to the following questions:-

1. What fish stocks are present and fishable within the area under consideration?

2. What are the general features of their biology? More particularly, what are the seasonal and geographic variations in distribution and in behaviour?

3. What is the magnitude of these stocks and how much should be caught? More specifically -
   (a) What is the optimum catch for each species?
   (b) What is the appropriate intensity of fishing for each species?
   (c) What fluctuations due to natural causes are to be expected in the numbers of each species; and consequently what modifications should be made, from year to year, in the estimated optimum catch and fishing effort as determined under (a) and (b) above?

Since the answers to these questions are continually being sought by the industry, and since they constitute the essential basis to any policy of management of a fishery, the selection of these questions needs no explanation. The attainment of these objectives requires extensive fundamental and applied research, as indicated in Table 1, and presupposes the establishment of a series of defined research objectives leading from one to the other; for this reason the work can best be regarded as falling into the three phases shown in the table.

It is advisable to refer here to a number of types of investigations, or interim projects, which have hitherto occupied considerable time in various programmes, and which have, from time to time, been regarded as the major or the principal part of the programme; it will be recognised, however, that in their true perspective, these projects constitute no more than important integral parts of the total programme.

The first of these interim projects was 'racial investigations'. It will be seen that these studies occupy a place in the appraisal phase of the investigation of the fish stocks. They received considerable attention from workers of the 'continental' school, particularly from Schmidt and Schnackenbeck between 1900 and 1930. The latter was investigating herring races, and the former more general problems. Although these enquiries serve as a focusing glass for drawing together a wide spectrum of biological information in respect of morphological variation, growth rates, spawning habits, etc., nevertheless it is to be understood that they must properly be regarded as part of an introductory phase.

Solution of the "over-fishing problem" and of the question of the taking of "undersized fish" has at times appeared to be a final objective. It has definite functional

continuity with two of the true objectives stated above, namely, optimum catch and appropriate intensity of fishing, but it will be appreciated that the earlier studies covered only part of these fields. Thus, over-fishing is one only of three possible conditions of a fishery. The determination of the condition of a fishery is a necessary preliminary to a thorough analysis which permits the calculation of the optimum catch to be taken, and of the intensity of fishing required to obtain that catch.

The study of age-composition of stocks, and of variations in growth, have from time to time emerged as major assignments for the fishery research worker, but it will be seen that these are what is described here as 'interim projects', which can be assigned appropriate positions in the full range of enquiry.

3. THE OBJECTS OF INVESTIGATION.

Table 1 is divided horizontally into three major sections (of which the last is subdivided into two) corresponding to the three major fields of enquiry listed in the column of the extreme left. Each section commands different sets of investigational procedures, which in early stages are carried out independently but become more and more closely integrated as the programme proceeds and results accumulate.

The final integration of the available techniques for the purposes of the *ad hoc* tasks of fisheries biology is represented in Fig. 5. It is a regrettable feature of this diagram that it presents, without differentiation, a number of different logical categories; thus, there are included:

(1) The physical objects of investigation.

(2) Certain salient factors which are in effect measurements of the operation of other objects.

(3) Raw data which are measurements of the quantity of parts of the physical objects.

(4) Derivative data resulting from the preceding category.

(5) Investigational operations.

(6) Parameters of the population.

(7) Objectives of investigation.

however, provided this deficiency, which cannot conveniently be overcome, is recognised the diagram should serve to indicate the relationships under discussion. As a preliminary, the components of which Fig. 5 is composed are shown in Fig. 1 without connecting lines; they are, however, grouped for the purposes of this section. Thus compartment 1 contains the investigational data and procedures relating to the Environment and also portion of the Fish Stocks; compartment 2 relates to the Fish Stocks, compartment 3 to Commercial Operations, and compartment 4 to the Fish Stocks.

In order to indicate fully the scope of the enquiries,

TABLE 1 - A PROGRAMME FOR

Objects of Investigations	Investigational
	A. of Exploration
I. FISH STOCKS	Experimental field operations, spot sampling. Aerial observations. Elementary biological observations, special occurrence and distribution, general features of biology - migrations, feeding habits, embryonic and larval history. Survey of popular knowledge.
II. COMMERCIAL OPERATIONS	Where stocks are newly discovered this section is concerned with observation of development of the fishery. For existing fisheries: Survey and description of equipment, methods, and personnel. Compilation of statistical data.

AUSTRALIAN FISHERIES.

Procedures in Phases:-

B. of Appraisal	C. of Control
Racial investigations to delimit stock units. Systematic sampling in field and market to determine biological properties of each unit of stock (i.e. reproductive and growing potentials). Experimental fishing operations. Tagging operations to determine movements, growth, population numbers. Planktonic study of fish eggs and larvae. Stomach content analysis to determine feeding. Age and growth studies. Gonad studies.	Routine maintenance (particularly of critical sections) of programme as under B, in order to permit sustained link-up with analysis of commercial operations, as trends and relations.
(Extension of analysis from systematic (sampling above, into the more comprehensive (sampling represented by commercial landings	
Collection of comprehensive statistics on - i. catch - a. by species, b. by localities, c. by units of time. ii. effort involved (represented by men, boats, and gear, and capital investment). Analysis of secular trends (isolation of cyclical fluctuations and exposure of erratic residuals). Analysis of relationship between - i. yield, ii. factors internal to the fishery - a. biological, b. environmental, c. economic, iii. factors external to the fishery (economic and psychological) affecting market.	Statement of controls on fishing to obtain implementation of conclusions as to adjustment of catching capacity of the fishing equipment and personnel to the various biological potentials of the stocks.

(Contd.)

TABLE 1

Objects of Investigations	Investigational
	A. of Exploration
III. ENVIRONMENT (a) Biological elements:- Plankton Nekton Seston	Spot sampling (with identification and enumeration of contents) by - locality, strata, seasons, and years. Systematic exploratory sampling for - i. Identification of biological character of environment. ii. Determination of distribution of major elements. iii. Determination of principal features of the "ecology" of the stocks.
	(The correlation of biological) (and abiological elements)
(b) Non-biological elements:- Climate Seawater Sea bottom	Spot sampling (observation of physical properties and analysis of chemical properties) by - locality, strata, seasons, and years. Systematic exploratory sampling for identification of principal water masses.
	This phase provides answer to - 1. What fish stocks are present and fishable within the area under consideration? 2. What are the general features of their biology?

(CONTD.).

Procedures in Phases:-	
B. of Appraisal	C.. of Control
Systematic detailed sampling for - i. assessing productivity of the waters, ii. deriving correlations of these with observations of fish stocks. Detailed study of biology of major elements. Physiological experiments.	Routine observation of critical factors and indicator "species", as a means to the prediction of fluctuations in fish stocks.
(The correlation of biological and abiological elements)	
Systematic detailed sampling for determination of major features of diurnal, seasonal, and annual variation of the distribution, limits, and properties of principal water masses. Correlation of these with fish stocks.	Routine observation of critical factors as a means to the prediction of fluctuation in biological elements and particularly of fish stocks.
This phase completes the answer to Question 2 and gives tentative answer to Question 3 in sub-sections a and b; it also gives data fundamental to the answer of 3c. 3. What is the magnitude of these stocks and how much should be caught? More specifically - a. What is the optimum catch for each species? b. What is the appropriate intensity of fishing for each species? c. What fluctuations due to natural causes are to be expected in the numbers of each species; and consequently what modifications should be made, from year to year, in the estimated optimum catch and fishing effort as determined under a. and b. above?	Permits modification of answers to 3a and 3b, according to the answer, from year to year, to 3c. (see p. 8). Results in statement of - Optimum catch. Appropriate fishing intensity. Prediction of fluctuations.

it is desirable to give a fairly comprehensive definition of the objects of investigation. Moreover, it is desirable to summarize here the general properties of these objects, and to present some generalizations since the nature of the requisite investigational procedures will in this way be clarified.

(i) Fish Stocks.

These may be classified (according to the type of habitat occupied) into onshore and offshore groups, with the latter further divided into demersal and pelagic groups.

Stocks in general occupy fairly circumscribed areas; but some stocks are characterized by immobility and general stability (although this does not exclude natural fluctuations), whilst others are characterized by mobility, that is, by migrations which in probably every case follow well-defined patterns. These patterns are discoverable, being related, *inter alia*, to seasons and to various environmental factors, and as a consequence the movements are in many cases predictable.

Some stocks are composed of single species, others of two or more species or races. The primary biological problem is the identification of the unit population existing as a distinct biological entity. The absolute magnitude of the stocks and their relative density are together a function principally of the area of ground and of the volume and productivity of the waters. Each stock will strive to give full expression to its growth potential per unit of area; limits are, however, definitely imposed by the environment. Each stock will also naturally fluctuate about some steady level, the fluctuations being produced by the repressive properties of the environment reacting with the expansive properties of the population.

Biological analysis of the stocks seeks to determine the biological properties of each unit population. These properties are the basis to an understanding of the absolute numbers of the stock at any one time, and of the magnitude of the fluctuations. These properties may be listed as follows:-

1. age composition,
2. sex ratio,
3. reproductive groups,
4. fecundity of the respective groups,
5. survival value of the respective groups (including, chiefly, the ability to evade enemies and to secure food),
6. growth rate of each group.

The reproduction of a natural population is a direct function of the absolute numbers of the population; it is greatest at some point when the population is in its asymptotic phase of 'balance', although, at that time, the survival numbers and rates may both be lower than at earlier periods in the history of the population. In the asymptotic, 'balance' stage of the population, reproduction and mortality are in equilibrium and the whole of the reproduction is

devoted to maintenance of the population; at earlier stages the actual reproduction is less but the surviving portion of each period's reproduction is in excess of the requirements for maintenance; this excess is greatest at that point, in the history of the population, represented by the point of inflexion of the sigmoid curve depicting the growth of the population.

In any biological period* the population tends to increase in numbers by reproductive activities, and in mass by the growth in mass of each of its individuals. This tendency is off-set by the repressive effect of mortality. A population, whether expanding, decreasing, or remaining at equilibrium, will fluctuate in numbers (and also in total weight) about its trend line.

Reproductive capacity of each population is the resultant product of sex ratio, reproductive proportions of the age groups, and the fecundity of these. Sex ratio is variable as between species and as between age groups; in most commercial species, however, there is approximate equality.

The age at which individuals become mature is a somewhat variable character, ranging from a few months to as much as ten years. In many species the individuals do not mature uniformly at the one age, but maturation of each year's brood is spread over a number of years. The presence of post-reproductive groups has not yet been clearly demonstrated for any species, but is suspected.

Fecundity is variable as between species and as between age-groups within the species. Some species produce tremendous numbers of eggs per fish at each spawning.

Spawning may be considered in respect of :

a. time of the year in which it takes place;

b. frequency for each individual within each season; and

c. locality, in terms of geographic location, depth, and various physical and chemical properties of the water.

In respect of these features a given year's spawning may be found to have occurred in most favourable circumstances, or in moderate or bad circumstances. In conjunction with the data on potential reproductive capacity this provides a basis to the understanding of the fluctuations in the abundance of successive age-groups.

Spawning is usually preceded by some specific type of behaviour; in the majority of cases this takes the form of a congregation into spawning shoals, which embark upon migrations of variable magnitude to suitable spawning areas. During this period, and sometimes during the actual spawning period, the stocks become most vulnerable to fishing operations.

Eggs may be pelagic (in mid or surface water) or demersal (fixed to objects on the bottom). It is possibly true that the fecundity of species whose eggs are pelagic is greater than that of species with demersal eggs. In both situations the eggs are subject to predation and to environmental factors.

* By biological period is here meant the interval between the commencement of one spawning and the commencement of the next.

Embryonic development varies from a matter of hours to a matter of weeks. There is reason to suppose that the length of the embryonic period, which is doubtless determined to a large extent by prevailing temperatures, itself determines certain meristic features, (e.g. the number of vertebral segments).

Larval stages may be pelagic or demersal, and may occupy the same habitat as the adult, or they may move through a series of habitats before finally entering that of the adult.

Degree of longevity is extremely variable, and partly associated with this is a variability in the normal and maximum sizes attained.

In addition to the movements of the fish associated with spawning, there are at times other movements of which those related to feeding are the most important.

Data on these subjects permit of estimates of growth and reproductive potentials of the population. These estimates must then be considered in relation to data on environmental factors, and this permits in the first place, a refinement of the estimates, and, in the second, a means of predicting the changes in the population which result from the interaction of the potentials with the environment.

Among the stocks subject to commercial exploitation there are a number of dominant types. Of the pelagic stocks there are, taxonomically, two major groups, the clupeoid and the scomberoid. The former comprises herrings, pilchards, anchovy, and sprats, the latter tunas, mackerels, and allied species. In both these groups the fish occur in large schools, the occurrences in any one locality or zone being distinctly seasonal. The clupeoids are at one end of the scale of size among fish and the tunas towards the other. Reproductive otential in both is great, and both are subject to fluctuation. The scomberoids show the greater apparent variation in abundance; this is possibly due to their greater migrations, which would cause variations in local accessibility, as distinct from variations in actual abundance. Of the demersal stocks there are two major groups: the flatfish (halibut, flounders, plaice, sole, etc.) and the gadoids (cod, haddock, whiting, saithe, etc.). The distribution of stocks of these fish is wider (over defined grounds), and is more homogeneous, than the distribution of pelagic stocks; there is less movement; reproductive and growth potentials are great. An intermediate group of tremendous importance is that comprising the true salmons which feed at sea and ascend rivers for spawning purposes. Finally, onshore stocks comprise great numbers of species; these are not capable of yielding catches comparable with those from the five groups already named, probably because they occupy relatively restricted areas.

Fluctuations in abundance of fish have always been a major feature of the associated fisheries. These fluctuations may be classified into real and apparent, the latter being in fact variations in the accessibility of the stocks to fishing operations, or in the conditions under which fishing may be conducted. Varying success in fishing operations is the result. The real fluctuations may be in numbers, or in the relative abundance of the age-groups of which the stock is composed, or in the sizes of the individual groups. Changes in abundance of component age-

groups cause fluctuations in the number of fish available and also variations in the average weight of the fish comprising the commercial catch.

(ii) Commercial Operations.

These may be regarded from two points of view, and considered in relation to three sets of factors.

In the first point of view commercial operations are responsible for producing catches which may be regarded as large samples, and dealt with accordingly, so as to constitute an important item of raw material for these investigations. In the second point of view they influence strongly the fish stocks under consideration, by the extent to which, in supplementing natural mortality, they remove fish and reduce the reproductive potential.

The first of the sets of factors referred to comprises external economic forces determining the vigour and intensity of operations. In part this set may be summed in the phrase 'effective demand'; but in addition there are some other effects produced by the direct operation upon components of the commercial system of such factors as competition for labour and for capital. The second set of factors is contained within the commercial system itself, and includes degree of efficiency of operation, and variations in the enthusiasm and application of the operatives. The third set of factors is presented by the fish stocks and their environment: those referring to the stocks include the limits of production, the liability to and the range of fluctuation, also the predictability of these; those referring to the environment include the physical suitability of the grounds to fishing operations. All these factors must be considered comprehensively in studying and drawing conclusions from commercial operations.

Under most conditions the commercial catch may be accepted as constituting a direct representation of the stocks (of fish of commercial size) from which they were drawn. At times adjustments must be made to allow for special selection by the fishing gear. The exclusion of certain juvenile groups is to be taken for granted. It is part of the biological programme to extrapolate the biological analysis into the commercial landings and obtain thereby an assay based upon the more extensive material of the latter.

Commercial operations may be classified according to the habitat of the fish which they exploit, to the season in which they are prosecuted, and to type of gear and vessel used. The major fisheries are naturally associated with the major types of stock listed above.

Considerable difficulty attends the measurement of effort involved in taking a catch of fish. Direct estimates are sometimes possible, e.g. in trawling, the catch per hour, per 10 hours, or per 100 hours, or, as a better estimate, the amount of ground which is traversed by such a net. Again, there may be recorded the number of hours in which stated lengths of mesh nets have been set in water, and these can be reduced to standard units. Estimates are frequently, however, in the form of man-days or man-years or boat-years, without any or much regard for differences of efficiency or of amount of time spent in actual fishing. Allowance must be made for time spent in scouting for fish shoals. Changes in gear employed present considerable difficulties. They are not easy to calibrate. They include change from sail

to power, or from one form of net to an improved form.

These problems must be considered when the interpretation of commercial statistics as indicators of conditions obtaining in the fish stocks themselves is being attempted. They really constitute sources of bias in sampling. If adjustment can be made to allow for these groups of factors, then the residual variations in the yield can be taken to correspond with similar variations in the natural stocks, subject, however, to a major reservation arising out of the effect upon the stocks of the fishing operations. This problem is a complex one as yet some distance from solution. Fishing operations effect abstractions from the stocks: these abstractions must be regarded both from the quantitative effect of the numbers removed and from the qualitative effect of the particular groups removed. In whatever way the figures may be adjusted, the quantitative relationship of catch to the natural stocks requires much further consideration. A further problem relates to the representation by the catch of the composition of the stocks; in this connection the selective effects of the nets are important.

An important interim project, which is dependent largely upon commercial statistics, is the diagnosis of the 'condition' of the fishery; that is, the determination of whether fishing is excessive, sustainable, or below what can be sustained by the stocks. The range of relevant material requiring consideration may be indicated by the following table of criteria to be employed in arriving at an answer.

A. Economic criteria:

I. Actual secular trend of catch, and of fishing units.

II. Adjusted trends:
i. Adjustment being made for factors external to the fishery, e.g. population movements.
ii. Adjustment being made for internal factors of the fishery, e.g. gear efficiency indices, giving derived indices of catch per fishing unit.

III. Multiple regression of catch on economic and environmental factors.

B. Biological criteria:

I. Direct estimates of population strength.

II. Range and slope of the population mortality curve, with age composition of the catch.

III. Average size of the catch.

IV. Average size of each age group.

C. Circumstantial and anecdotal evidence.

Certain characteristic features within each of these criteria are presented by virgin, over-fished, well-fished, and under-fished stocks.

Finally, it should be noted that it is a cardinal

principle of this work that fishing operations are to be regarded as being to some degree beneficial to the stocks. The removal of older fish, and the general thinning-out of the stocks, have the effect of rejuvenating the stocks, placing the emphasis (of age-composition) upon the younger groups which have better growing potential, and removing large predators. This feature must be held in mind in planning control on fishing.

(iii) The Environment.

The factors and elements of the environment which affect the fish stocks can be considered in two groups, biological and non-biological. The view of water-masses as distinct entities of almost biological organization, is gaining ground. This is indicated by discussions on the metabolism of such water-masses. Consideration of the cycles proceeding within water-masses, and of the exchanges made with other media, add to this view. It is therefore necessary to consider all elements as being closely involved one with the other.

(a) Biological Elements.- These can be arranged, according to principal features, into three groups:-

1. Plankton, which comprises those organisms which are very largely dependent for spatial movement upon the movement of their suspending medium. Includes larval and embryonic stages of many groups, especially of fish, and the adult stages of many others, e.g. Coelenterates, Crustacea, and Tunicata. It must also be taken to include marine bacteria.

2. Nekton, which are swimming organisms, including fish, various mammals, mollusca and a few other types.

3. Seston, the bottom-living organisms of somewhat sedentary character.

The study of the seston more nearly conforms to the classical concept of animal ecology, with its scope for quadrates, traverses, plotted distributions, and precisely estimated densities.

The nekton includes the bulk of commercially exploited fish stocks, as well as some non-commercial species.

The study of plankton is of such importance and complexity that an almost independent science is developing to accommodate it. Plankton consists of plant and animal groups. The phyto-plankton are the prime elements in organic production in the sea. The 'flowerings' of phyto-plankton in spring and autumn are a major feature of the biology of this group, and are complexly associated with physical and chemical properties of the seawater; on the other hand they are associated, by various predatory and non-predatory relationships, with the zoo-plankton and with the nekton and seston. The productivity of any water mass in terms of phyto-plankton is being measured by a number of workers, and promises to become a useful guide in evaluating these waters.

The study of marine bacteria is also assuming greater importance. The role of these organisms in the disintegration of dead organic material and in the cycles of nutrient salts is but little understood.

The taxonomic character of the plankton is found to be a reliable preliminary guide to the productive nature of

a water mass. Periodic fluctuations (of various time-durations) in the density and distribution of the plankton, as a whole and in respect of its components, provide material for extensive investigations, and would appear to be one of the basic causes of the extensive fluctuations to which the fish stocks are subject.

The occurrence of fish within the plankton, in the form of eggs or larvae, is a fact of considerable importance in relation primarily to the study of the biology of the fish, and, secondarily, to studies on the abundance and success of each year's spawning.

(b) Non-Biological Elements.- The primary element in this group is the seawater, constituting as it does the medium of existence of the biota. Climatic factors, being elements within the contiguous aerial medium, and the sea-bottom both influence the properties of the seawater and must be considered.

The major problem in this sphere is the identification of components of the principal water masses and the description of their chief characters, statically and dynamically. The general stability or otherwise of a water mass is of considerable importance; some masses are quite permanent, others have a very temporary existence. In this connection, the programme requires a broad survey of physico-chemical properties of the water masses and determination of the spatial and temporal distribution of these properties. The second problem is the elucidation of current systems within the area. Following this, and at times, concurrently, there should be detailed consideration of the chemical productivity of the area and of the factors which influence this productivity. Finally, there should emerge a system of prediction and behaviour of these elements, which, it should be stressed, will involve cognizance of the inter-related behaviour of meteorological and hydrological elements.

4. THE INVESTIGATIONAL PHASES.

Table 1 is divided vertically into columns corresponding to three stages of progress in this work. The general character of the investigational procedures changes from phase to phase. In actual practice these phases are by no means distinct; there is a merging of the procedures of one phase into those of the next, and there is clearly no standard length of time for the prosecution of any procedure. These phases, however, are real, and they represent developmental stages, wherein the activities of the various sections become fused and co-ordinated into the one common plan of investigation. Thus, in the first phase, all sections are working somewhat independently, accumulating isolated data whose analysis gives pointers as to the correlations which exist between these sections; in the second phase full analysis of these factors is sought and quantitative expression of the correlations is attempted; in the third phase, observations are made to permit the employment of these expressions in forming predictions. These are the normal developmental stages of a science. These phases may refer in general to all the enquiries in respect of the fisheries of an area or they may refer differentially to the species in an area.

It will be seen that in any area at any particular time the enquiries relating to, say, the environment could be well advanced and in phase B, whereas those relating to one particular species in the area were still little advanced.

Research programmes vary greatly in the point in this scheme at which they start. Some programmes start with absolutely no useful information as to the stocks under investigation, and with no fishery operating; others start with a considerable quantity of fishermen's lore, as to movements of the fish, habits etc., and a considerable bulk of statistical and other data relating to commercial operations. The latter was the case with regard to most fisheries of the Northern Atlantic, the North Sea, and adjacent waters; the former was the position here in Australia. These variations determine the amount and kind of work which must be done in the exploratory phase.

In practically every case there is some information drawn from more formal (academic) research. In the past, and continuing to the present, this type of work has borne upon elements shown in Fig. 1; this is indicated by the arrows in Fig. 2.

The appraisal phase contains the bulk of the work which is the responsibility of this science. It contains the planned systematic survey of the properties of all elements involved. In this phase the reproductive and growing potentials of the stocks are analysed and measured, the efficiency and intensity of the fishing operations are determined, and the properties of the environment, in providing food, space, and enemies, are revealed and measured. Also some advance is made in this phase in determining correlations.

Within the appraisal phase certain investigations may proceed somewhat independently. Thus, examination of racial composition and, associated with it, a preliminary analysis of recruitment potential is represented in Fig. 3. Again, an independent inquiry on the 'condition' of a fishery, considering only economic aspects, may be conducted as indicated in Fig. 4.

The final phase is one of discharging the social responsibilities of the science. The investigations can provide answers to the questions listed above, but, as indicated, these answers must be expected to change from year to year, and it is the responsibility of the investigators to maintain the work in order to continue the provision of the necessary information. This involves the essential extension work without which there is frustration. Programmes of this kind, conducted on behalf of the nation, by whom the bill is paid, should be implemented for the benefit of the nation, just as the findings of the medical, veterinary, and agricultural sciences are implemented and applied.

5. INVESTIGATIONAL PROCEDURES.

The programme must be regarded essentially as one of specialized and applied ecology. It involves extensive field observational work and collecting of samples, as well as corresponding extended work in the assimilation of such

material. On the other hand, the investigations must be supplemented by laboratory experimentation, and all sections of the enquiry borrow from fundamental research. Such borrowings are of information of deeper significance than that yielded by the routine investigations of the established programmes, and afford a guide to the development and extension of the general programme. Resulting enquiries are not shown in the table since they are not restricted by any scheme of fisheries investigations, they are drawn into the programme at the points marked in Fig. 2.

(i) Biological Investigations.

These comprise firstly general field observations on behaviour, feeding, spawning, and migration habits, and the study of distribution. Sampling of the fish stocks may be made by experimental netting operations, or simply from the commercial catches. Handling of such samples involves the measurement of various dimensions, weighing of whole fish and of parts, observation of stomach contents and gonad condition. Taxonomic procedures in counting fin-rays, scales, etc., and recording colours, may also be followed. Observations on surface occurrences can be made by means of aerial work.

Taxonomic procedures aim at the identification of the principal species and subsequently at detailed work in racial investigations. This work bears the responsibility of defining the limits of distribution of the principal bodies of the fish stocks.

Tagging operations, in which individual fish are marked with distinctive identification marks, yield information on the movement of fish (the groups which migrate, the time, direction, distance, and frequency of movement) and on the growth of the individual fish. Further, these operations can be employed in measuring population numbers and the intensity of fishing operations in relation to the abundance of the stock.

Age and growth studies are based upon biometrical techniques in dissecting frequency curves and upon an examination of scales, otoliths, and other hard structures which carry a record of important epochs in the life of the fish.

Gonad studies are the basis to estimations of fecundity and of reproductive potential, and to the determination of the age at first maturity.

Plankton studies are employed in determining the occurrence of pelagic eggs and larvae. This work provides the material for investigations into the early life-history of the fish and for determination of time and locality of spawning. Further examination can be made by these methods of the success (resulting fish abundance) of each year's spawning and of the survival and distribution of the larv and young fish.

Similar problems can be attacked by means of special apparatus for taking non-demersal eggs and larvae. In Fig. 5 these procedures occupy the greater part of the diagram. That is because the biological programme is so central to the entire enquiry.

(ii) Biometry and Econometry.

Considerable recourse is made to the methods of biometry

and statistics since, within the appraisal and subsequent phases, the objective is to obtain material on a systematic basis and to state the phenomena in quantitative terms. The double term is used to indicate that attention is shared between the specialized technique for treatment of quantitative biological data (e.g. the use of analysis of variance), and the use of methods regularized by economists for the treatment of time series in economic data.

The introduction of these techniques is progressing rapidly in this science as in other biological sciences, and there is already full scope for the application of most of them. In particular the use of the analysis of variance in racial studies and in plankton investigations, of covariance analysis in growth studies, of multiple correlations in reducing economic data, and of Fourier and other series in analysing fluctuations, promise to yield considerable advances in the treatment of this material.

(iii) Economic Investigations.

The actual collection of accurate statistics, grouped according to the listed variables, is the responsibility of administrative departments. However, the research programme is invariably presented with the problem of assessing the intensity of fishing, which involves an investigation of the efficiency of fishing gear of various types; often the problem is best resolved by the employment of some standard fishing gear in experimental vessels.

The collected statistics must first be adjusted for such variable factors as can be measured and then analysed for trend, and for seasonal, cyclical, and erratic fluctuations. Attempt must then be made to correlate these elements in the series with factors operating within the environment and also factors operating within the stocks themselves.

(iv) Planktological Investigations.

Field collection of plankton samples is generally made by means of tow-nets of various kinds. However, other kinds of gear, such as pumps and the automatic recorder, are also employed. Probably the most important problem in the essentially biological phases of planktology is that of sampling, involving problems in the adequacy and reliability of the catch taken and also in the 'design' of the sampling pattern.

Laboratory treatment of the catches includes estimation (as volume or weight) of the quantity of catch, and identification and enumeration of its contents. The latter work must be supported by special studies in the life-history of each species, and this may be regarded here as part of the taxonomic practice. Various alternative methods for evaluation of catches have been tried, e.g. colorimetric methods in measuring phyto-plankton.

A considerable advance has been made in these investigations by recent experiments on the physiology of the plankton, in measuring the productivity of the waters under investigation. This work is striking directly at the urgent problem of the relationship of the plankton to hydrological factors on the one hand and, on the other, to phenomena observed in the fish stocks.

(v) Hydrological Investigations.*

These may be considered within four principal departments.

A. Hydrography includes the charting of bottom contours and the collection of general data on winds and currents in an area.

B. Chemical oceanography includes:

1. The study of the distribution of significant elements (e.g. chlorinity, nutrient salts, dissolved gases), spatially, bathymetrically, and temporally.

2. The derivation of basic seasonal cycles of variation in the pattern of distribution of these elements and estimation of the factors causing big departures from this basic cycle. Development of prediction systems.

3. Estimation of the chemical productivity of the region by

a. Comparison of the basic pattern with that of other known regions.

b. Examination of the regional turnover of nutrients, involving a study of their vertical and horizontal distribution, the rate at which nutrient reserves are built up in the deeper layers, the rate at which they are transferred and the processes responsible for this transfer, to the upper phototropic zone. The rate at which the nutrients built up into the tissues of the plankton are converted, by the death, degeneration and autocatalysis of these organisms, into the basic nutrients must also be determined.

C. Physical oceanography comprises:

1. A study of the distribution of physical factors (e.g. temperature, density, light penetration), spatially, bathymetrically, and temporall

2. The derivation of basic seasonal cycles as for chemical elements.

3. Examination of the role of physical factors in the processes referred to in B(3)b above.

D. Hydrodynamical oceanography includes:

1. The construction from the physical data of dynamic charts showing the residual current patterns at different depths, the seasonal variation in these currents, the volume transport of water by major current components through the region, etc.

2. Use of other available methods (e.g. identifying properties, isentropic analysis) to support or amplify the conclusions of D(1).

3. Examination of the possible role of processes of lateral diffusion, vertical turbulence, in distribution of plankton, and particularly fish eggs, in the region. This work links with the study of chemical productivity under B(3).

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* I am indebted to Mr. D.J. Rochford for this statement of the hydrological techniques.

(vi) The Integrated Programme.

The full programme is represented in Fig. 5. Remarks have been made above upon the heterogeneous composition of this diagram, and it is to be recognized that the arrows are equally mixed; certain arrows represent effects of factors bearing upon elements, others represent lines of movement of information passing from raw condition to the refined state of simple deductions.

In Fig. 1 the same basic components were represented as divided off into compartments, and although that may be to some degree true in fact, the situation of mutual dependence represented here is also true in practice. There are, however, certain dominant lines of argument which should be recognized, and which may be described here.

The central argument is that certain parameters of the population can become known from the sampling of the population represented by commercial operations. This sampling is represented in the diagram at the point 'A'; test samples of this major abstraction are taken and, when supplemented by the experimental sampling direct from the population ('B') permit of measures of the relative composition of the population (in respect of sex, age, weight, and length). The necessity for weighting the samples must be stressed. From these relative measures estimates of population fecundity and growth rate can be prepared and, when combined with market measurements made in stratified sampling, will yield an estimate of the composition of the stock in each region. The last estimate of composition is then to be combined with the statistics of the weight of landings from each region to give a total estimate in numbers of the composition of the total catch, which combines with the relative estimates of population fecundity and of growth rate to give first estimates of the actual population potentials of reproduction and growth. (It is to be noted that the estimate of growth rate is to be modified in accordance with the data on the force of various environmental factors). Adjustment of the first estimates of these two population potentials in accordance with further information on the relationships of catch to natural population (from the tagging work and aggregation effects etc.) permits of definitive estimates of these potentials.

The second line of argument commences at point 'C' with the statistics of commercial operations which give data on number of fishing units operating per unit time and on the character of the equipment, from which measures of efficiency are drawn. When these two are combined with data on the landings from commercial operations, a raw figure of catch per unit is prepared which is then adjusted on the basis of data in respect of aggregation effects in the population, of selective effects in fishing, of weather conditions, and of prevailing economic conditions (market etc.). The adjusted catch per unit is then dissected on the basis of the estimate of composition of total catch in numbers as derived from argument 'A'; the resultant analyses and adjusted catch per unit are then employed in an estimate of mortality rates, which, with supplementary data, can be partitioned between fishing and natural causes and made absolute, rather than only rates.

The third line of argument commences at the definitive estimate of total reproduction potential of the population ('D' in the diagram). An estimate of the amount of spawning to be expected is drawn from this and is combined with data from planktological (or other) work on the abundance of eggs, and from environmental investigations on the force of environ-

mental factors affecting the eggs, to give an estimate of the actual abundance of viable eggs spawned. This in turn is combined with similar data from planktology and environment investigations to give an estimate of larvae; and again an estimate of young fish. This estimate, combined with data on population composition, yields an estimate of the recruitment into the population.

Finally, data on tagging releases and returns, combined with data on recovery of efficiency, etc. and with data on numbers and composition of catch, yield information applicable to the first two arguments.

From these parameters can then be drawn estimates of the two quantitative features of the population which it is required to know in order that the questions originally set out may be answered. The properties are, the actual numbers of the populations in each biological group, and the actual weight. It is on the basis of these, and the actual lines of argument described, that the optimum catch and the appropriate intensity of fishing will be specified.

6. DISCUSSION.

The foregoing account of the programme for fisheries biological investigation is intended to give the broad lines along which such programmes may be developed and the general terms and objectives of the programmes. It is also intended to show that fisheries biology is a specialized science, a field of applied ecology, with some measure of autonomy. There is considerable dependence upon the fundamental sciences for techniques and for data but, having received these it employs them in a way and with objectives differing from those of other biological sciences, both in manner and degree. This science is more than the discovery of spawning places or the delineation of migrations, although it requires these data. It is more, too, than the diagnosis of 'depletionary' conditions or prognosis of future course, and it is fundamentally erroneous to say that the fisheries biologist is helpless until depletion occurs. The science is active and independent, and has a distinct contribution to make.

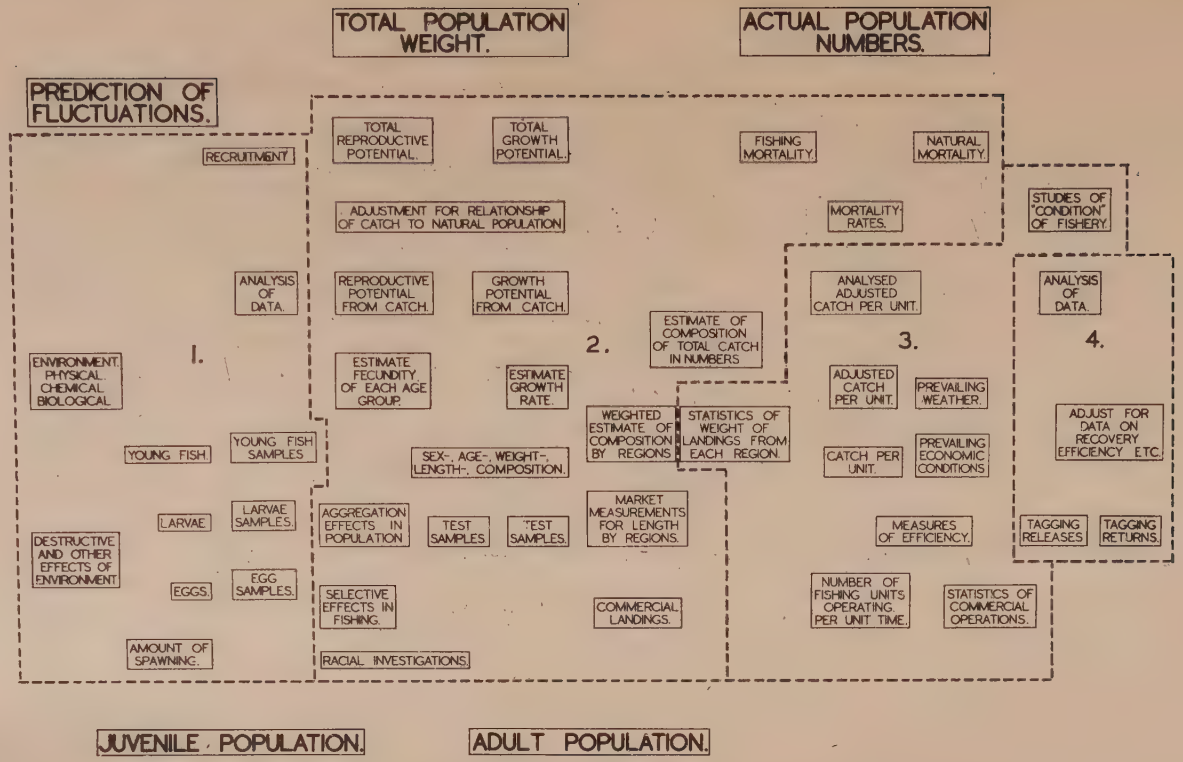
An attempt has been made above to stress three major ideas:-

(a) the phasic character of the development of the programme which requires that at certain times certain methods are employed and at other times other methods;

(b) the necessity for ultimate achievement of integration of the programme for a single purpose;

(c) the concentration upon the study of population properties (and the factors affecting those properties). The assessment of these properties is basic to the population equation which in turn is basic to the management policy.

The theory of fisheries exploitation, in its modern formulation, recognizes the importance of assessing population properties, and states that the removal by fishing should be balanced with the removals by natural mortality, against recruitment; this must be done not only in respect of numbers in a given year, but also in respect of the growing and reproductive potentials of the population during a longer period. The present paper has endeavoured to describe the programme in which this is done.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PREDICTION OF FLUCTUATIONS.
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TOTAL GROWTH POTENTIAL.
FISHING MORTALITY.
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Fig. 1.

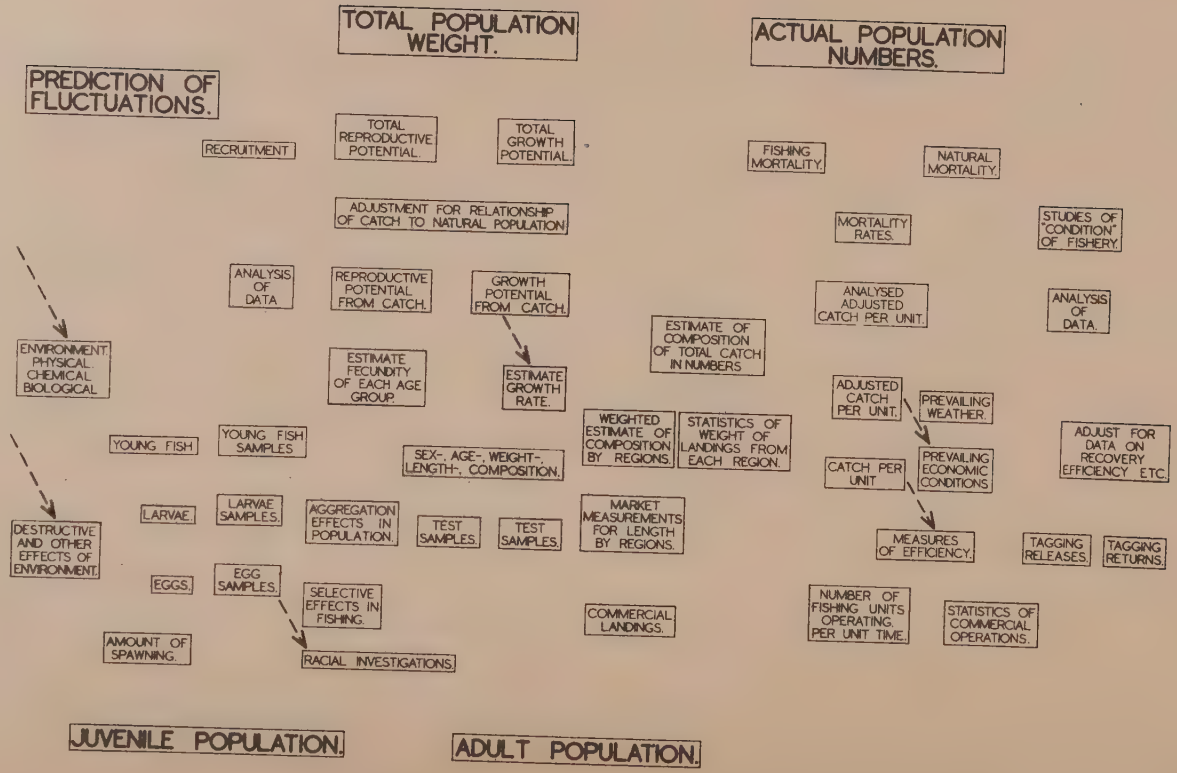
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Fig. 2.

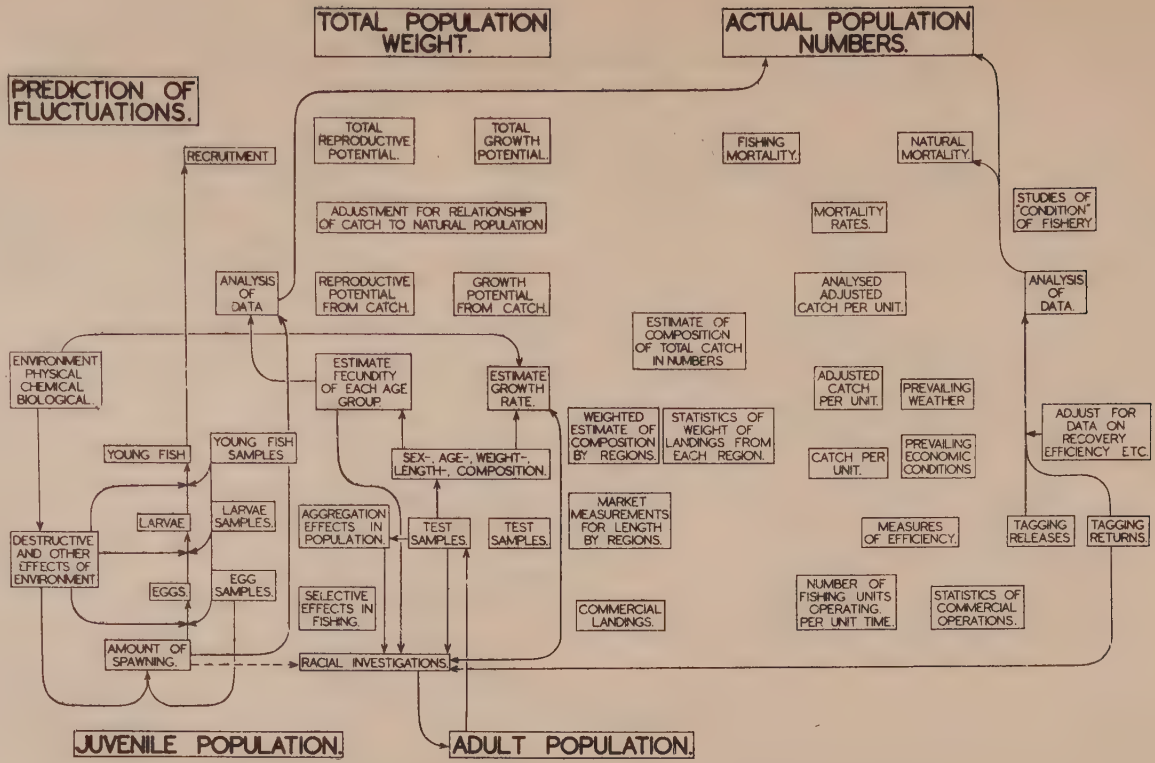
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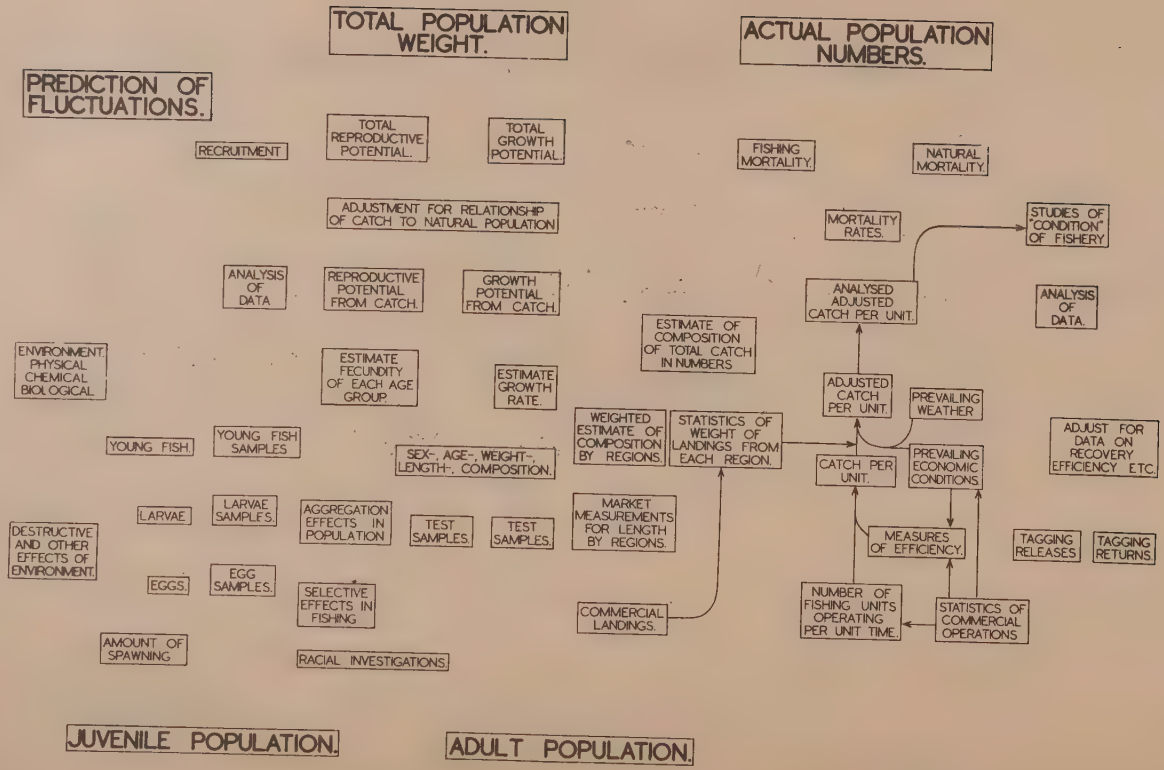
Fig. 3.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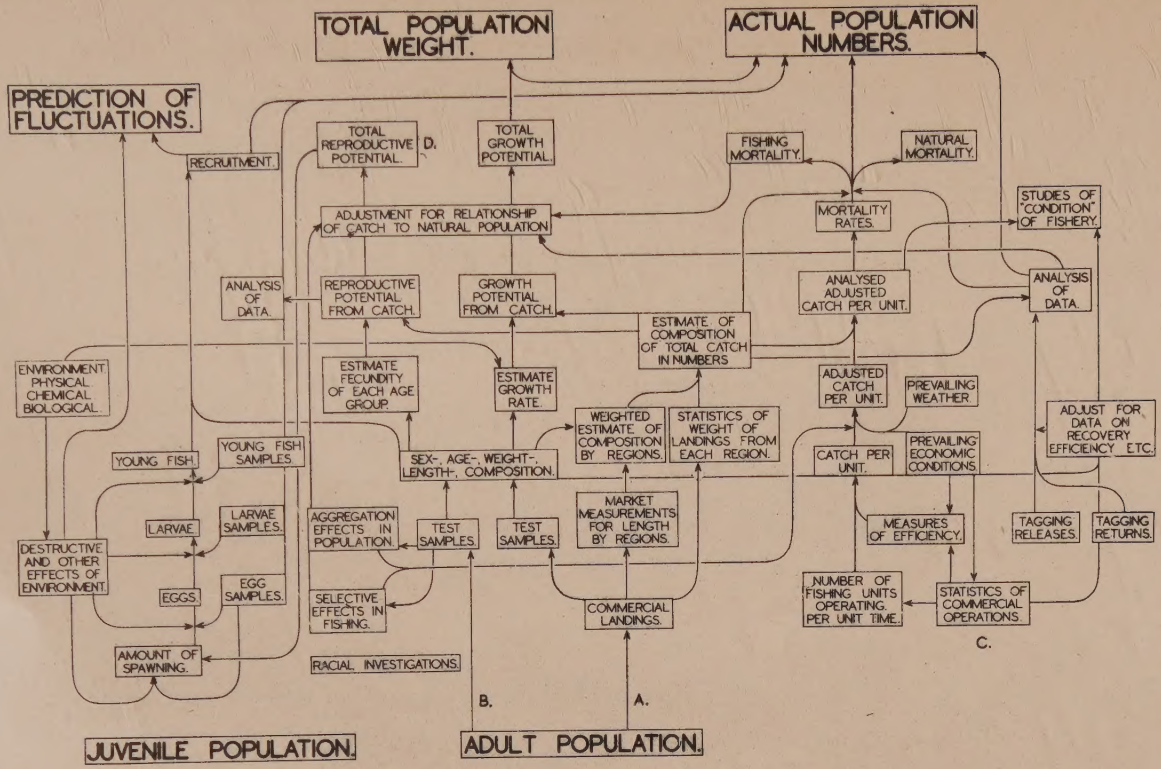
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Fig. 5.

The following list gives the

BULLETINS

numbered from 120 onwards.

A full list of the Council's publications is issued as a Supplement to the Council's Journal for February each year.

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120. Some Effects of Green Manuring on Citrus Trees and on the Soil
121. Observations on the Toxicity of Fluorine for Sheep
122. The Establishment of Pastures on Deep Sands in the Upper South-East of South Australia
123. A Soil Survey of the Merbein District, Victoria
124. The Wood Anatomy of Some Australian Meliaceae with Methods for their Identification
125. A Soil Survey of Part of the Kerang Irrigation District, Victoria
126. Investigations on Chilled Beef. Part I.—Microbial Contamination Acquired in the Meatworks
127. Radio Research Board: Report No. 14
128. An Investigation of the Problems of Salt Accumulation on a Mallee Soil in the Murray Valley Irrigation Area
129. Investigations on Chilled Beef. Part II.—Cooling and Storage in the Meatworks
130. Chemical Investigations on the Fleece of Sheep
131. Black End and Anthracnose of the Banana with Special Reference to Gloeosporium musarum Cke. and Mass.
132. The Wood Anatomy of Some Australian Lauraceae with Methods for their Identification
133. A Soil Survey of the Mildura Irrigation Settlement, Victoria
134. Studies on Bovine Mastitis. 1.—Study of an Experimental Herd
135. Investigations on the Storage of Jonathan Apples grown in Victoria
136. Experimental Studies of Ephemeral Fever in Australian Cattle
137. A Soil Survey of the Red Cliffs Irrigation District, Victoria
138. The Economic Biology of Some Australian Clupeoid Fish
139. The Soils of Tasmania
140. Foot-Rot in Sheep: A Transmissible Disease due to Infection with Fusiformis nodosus (n. sp.). Studies on Its Cause, Epidemiology, and Control
141. A Soil Survey of the Waikerie Irrigation Area, South Australia
142. A Soil and Land Use Survey of the Hundreds of Riddoch, Hindmarsh, Grey, Young, and Nangwarry, County Grey, South Australia
143. Production of Dried Grapes in Murray Valley Irrigation Settlements. 1.—Viticulture
144. Interference in a Wind-Tunnel of Octagonal Section
145. Friction and Lubrication: Report No. 1
146. An Analysis of the Outbreaks of the Australian Plague Locust (Chortoicetes terminifera Walk.) during the Seasons 1937-38 and 1938-39
147. Enzootic Ataxia and Copper Deficiency of Sheep in Western Australia
148. Studies in Fertility in Sheep. 2. Seminal Changes Affecting Fertility in Rams
149. Production of Dried Grapes in Murray Valley Irrigation Settlements. 2. Irrigation, Drainage, and Reclamation
150. The Soils of the Parishes of Longford, Cressy, and Lawrence, County Westmorland, Tasmania
151. The Control of St. John's Wort (Hypericum perforatum L. var. angustifolium D.C.) by Competing Pasture Plants
152. Soil Survey of Part of County Moira, Victoria, including the Parishes of Boosey, Cobram, Katamatite, Naringaningalook, Katunga, Yarroweyah, and Strathmerton
153. Pelagic Tunicates in the Plankton of South-eastern Australian Waters, and Their Place in Oceanographic Studies
154. The Handling and Storage of Australian Oranges, Mandarins, and Grapefruit
155. Friction and Lubrication: Report No. 2. The Lubricating Effect of Thin Metallic Films and the Theory of the Action of Bearing Metals

BULLETINS—*continued*

156. Standardized Plant Names
157. Studies in the Biology of Australian Mullet. 1.
158. The Recovery of Inter-block Information in Quasi-Factorial Designs with Incomplete Data. 1.
159. Poisonous and Harmful Fishes
160. The Outbreak of the Australian Plague Locust (Chortoicetes terminifera Walk.) in the Season 1939-40, with Special Reference to the Influence of Climatic Factors
161. A Review of the Evidence Concerning Expansive Reaction between Aggregate and Cement in Concrete
162. The Soil and Land-Use Survey of the Wakool Irrigation District, New South Wales
163. Transmission of Potato Virus Diseases. Parts 1 and 2
164. Studies in the Biology of the Skin and Fleece of Sheep. Parts 1, 2, and 3
165. Potato Virus X.: Mixtures of Strains and the Leaf Area and Yield of Infected Potatoes
166. Fertility in Sheep. An Experimental Study of Periodicity of Oestrus and Non-breeding Seasons in Australia
167. The Detonation of Nitroglycerine by Impact (*Not for distribution*)
168. A Survey, Census, and Statistical Study of the Horticultural Plantings on the Murrumbidgee Irrigation Areas, New South Wales
169. The Entomological Control of St. John's Wort (Hypericum perforatum L.) with Particular Reference to the Insect Enemies of the Weed in Southern France
170. Pea Mosaic on Lupinus varius L. and other species in Western Australia
171. Experiments with Insecticides against the Red-legged Earth Mite (Halotydeus destructor (Tucker)).
172. Zebu-cross cattle in Northern Australia. An Ecological Experiment
173. The Detonation of High Explosives by Impact (*Not for distribution*)
174. Recent Advances in the Prevention and Treatment of Blowfly Strike in Sheep
175. The Recovery of Inter-block Information in Quasi-Factorial Designs with Incomplete Data. 2.
176. The Analysis of Cubic Lattice Designs in Varietal Trials
177. A Soil Map of Australia
178. Food Composition Tables
179. Lubrication between the Piston Rings and Cylinder Wall of a Running Engine
180. Studies on Deglutition in Sheep. Parts 1 and 2
181. Sheep Blowfly Investigations. The Attractiveness of Sheep for Lucilia cuprina
182. The Effectiveness of Various Mineral Dusts for the Control of Grain Pests
183. Experimental Determination of the Influence of the Red-legged Earth Mite (Halotydeus destructor) on a Subterranean Clover Pasture in Western Australia
184. Fellmongering Investigations. Papers I. to XII.
185. Studies on the Mitchell Grass Association in South-Western Queensland. 2.
186. The General Ecological Characteristics of the Outbreak Areas and Outbreak Years of the Australian Plague Locust (Chortoicetes terminifera Walk.)
187. Alcohol: Its Place in Synthetic Organic Chemical Industry
188. A Soil, Land-Use, and Erosion Survey of Part of County Victoria, South Australia, including the Hundreds of Belalie, Whyte, Reynolds, and Anne, and Part of the Hundreds of Caltowie, Yangya, and Bundaleer
189. Soils of the Berriquin Irrigation District, N.S.W.
190. Foundry Sand Resources of South Australia
191. Studies of the Physiology and Toxicology of Blowflies. Parts 10 and 11
192. Investigations of Guayule (Parthenium argentatum Gray) in South Australia
193. Post-Miocene Climatic and Geologic History and Its Significance in Relation to the Genesis of the Major Soil Types of South Australia
194. A Procedure of Investigation in Fisheries Biology